Materials and Design 32 (2011) 4004–4009

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Short Communication

Production and characterization of AA6061–B_4C stir cast composite

K. Kalaiselvan [a,*], N. Murugan [a,1], Siva Parameswaran [b,2]

[a] Department of Mechanical Engineering, Coimbatore Institute of Technology, Coimbatore 641 014, Tamil Nadu, India
[b] Department of Mechanical Engineering, Texas Tech University, Lubbock, TX 79409, USA

ARTICLE INFO

Article history:
Received 23 December 2010
Accepted 8 March 2011
Available online 15 March 2011

ABSTRACT

This work focuses on the fabrication of aluminum (6061-T6) matrix composites (AMCs) reinforced with various weight percentage of B_4C particulates by modified stir casting route. The wettability of B_4C particles in the matrix has been improved by adding K_2TiF_6 flux into the melt. The microstructure and mechanical properties of the fabricated AMCs are analyzed. The optical microstructure and scanning electron microscope (SEM) images reveal the homogeneous dispersion of B_4C particles in the matrix. The reinforcement dispersion has also been identified with X-ray diffraction (XRD). The mechanical properties like hardness and tensile strength have improved with the increase in weight percentage of B_4C particulates in the aluminum matrix.

1. Introduction

Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, it is widely used in aerospace, automobiles, marine etc. [1–3]. The aluminum matrix is getting strengthened when it is reinforced with the hard ceramic particles like SiC, Al_2O_3, B_4C etc. resulting in enhanced wear resistance and strength to weight ratio than the conventional alloys [3,4]. Based on the type of reinforcement, size and morphology, the AMCs are fabricated by different methods such as stir casting, squeeze casting, spray deposition, liquid infiltration, and powder metallurgy [5,6]. In casting process, the reinforcing elements such as metal carbides, metal borides, metal nitrides and metal oxides are dispersed within molten alloy matrix under atmospheric pressure. But in the powder metallurgy route, the reinforcing elements are blend with matrix powder and distributed evenly throughout matrix and it is subjected to sintering as followed by plastic working.

Among the manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs [7] as it is relatively inexpensive and offers a wide selection of materials and processing conditions [8,9]. Stir casting offers better matrix-particle bonding due to stirring action of particles into the melts. The recent research studies reported that the homogeneous mixing and good wetting can be obtained by selecting appropriate processing parameters like stirring speed, time, and temperature of molten metal, preheating temperature of mould and uniform feed rate of particles [10].

Conventional stir casting involves adding ceramic particles into the melt in the crucible which is kept inside the furnace. The melt is transferred to permanent mould after stirring. Modified stir casting involves directly transferring the melt into a permanent mould with a bottom pouring arrangement attached to the furnace [11,12].

A limited research work has been reported on AMCs reinforced with B_4C due to higher raw material cost and poor wetting. B_4C is a robust material having excellent chemical and thermal stability, high hardness (HV = 30 GPa), and low density (2.52 g/cm^3) and it is used for manufacturing bullet proof vests, armor tank etc. In nuclear power plant, Al–B_4C composites (Boral and Metamic) are used as neutron absorber [13]. Hence, B_4C reinforced aluminum matrix composite has gained more attraction with low cost casting route [8,9,14]. In this paper, fabrication, characterization and evaluation of mechanical properties of produced AMCs reinforced with B_4C are detailed.

2. Experimental procedure

2.1. Fabrication process

The proposed AMC was produced using AA6061-T6 alloy having the chemical composition as shown in Table 1. The ultimate tensile strength of cast AA6061 was found to be 160 MPa. The micro and macrohardness of cast AA6061 were 45 VHN and 30 BHN respectively. The reinforcing particle was B_4C with a mesh size of 10 µ. As B_4C wetability with Al matrix is poor K_2TiF_6 flux was added to the melt during stir casting process [9].

* Corresponding author. Mobile: +91 9443952292.
E-mail addresses: jayakalai@rediffmail.com (K. Kalaiselvan), murugan@cit.edu.in (N. Murugan), siva.parameswaran@ttu.edu (S. Parameswaran).
[1] Presently in Texas Tech University as International visiting scholar. Tel.: +91 422 2574071, 2574072, mobile: +91 9751824123; fax: +91 422 2575020.
[2] Mobile: +1 806 5770236, tel.: +1 806 7423563x246.

0261-3069/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.matdes.2011.03.018

Table 1
Chemical composition of aluminum alloy (6061-T6).

Elements	Mg	Si	Fe	Cu	Mn	Cr	Zn	Ti	Al
% by weight	0.95	0.54	0.22	0.17	0.13	0.09	0.08	0.01	Balance

A batch of 1250 g of aluminum alloy was melted at 920 °C using an electric furnace shown in Fig. 1. The melt was agitated with the help of a mechanical stirrer to form a fine vortex [15–16]. The mixtures of preheated B_4C particles with an equivalent amount of K_2TiF_6 flux (with 0.1Ti/B_4C ratio) were added at a constant feed rate into the vortex. The process parameters employed are given in Table 2. Argon gas was supplied into the melt during the operation to provide an inert atmosphere. After stirring the molten mixture, it was poured down into the preheated permanent mould. The AMCs having different weight percentages (4, 6, 8, 10 and12) of B_4C were fabricated by the same procedure. The manufactured typical AMCs are shown in Fig. 2.

2.2. Microstructure and testing

A color metallographic study was carried out on the fabricated AMCs using optical microscope and scanning electron microscope. The XRD analysis, hardness and tensile tests were also carried out.

The specimens prepared from the casted AMCs were polished and etched as per the standard metallographic procedure. The microstructures of color etched specimens were observed using a metallurgical microscope (Olympus Microscope – BX51M) and scanning electron microscope attached with energy dispersive spectroscope (JEOL JSM-6390). The color etchant used to reveal

Table 2
Process parameters of modified stir casting.

Parameters	Units	Value
Spindle speed	RPM	300
Stirring time	min	5
Temperature of melt	°C	920
Preheated temperature of B_4C particles	°C	400
Preheated temperature of mould	°C	250
Powder feed rate	g/s	0.8–1.2

Fig. 2. The manufactured stir cast AA6061–B_4C composites.

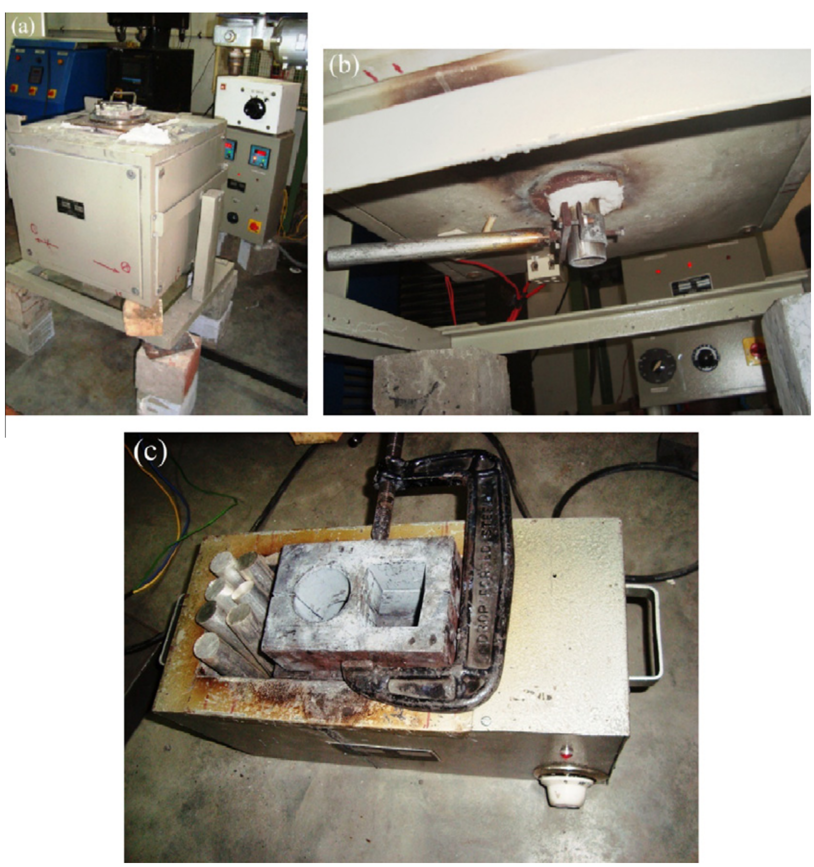

Fig. 1. Modified stir casting equipment facility: (a) electrical furnace, (b) bottom side of the furnace, and (c) preheated permanent mould.

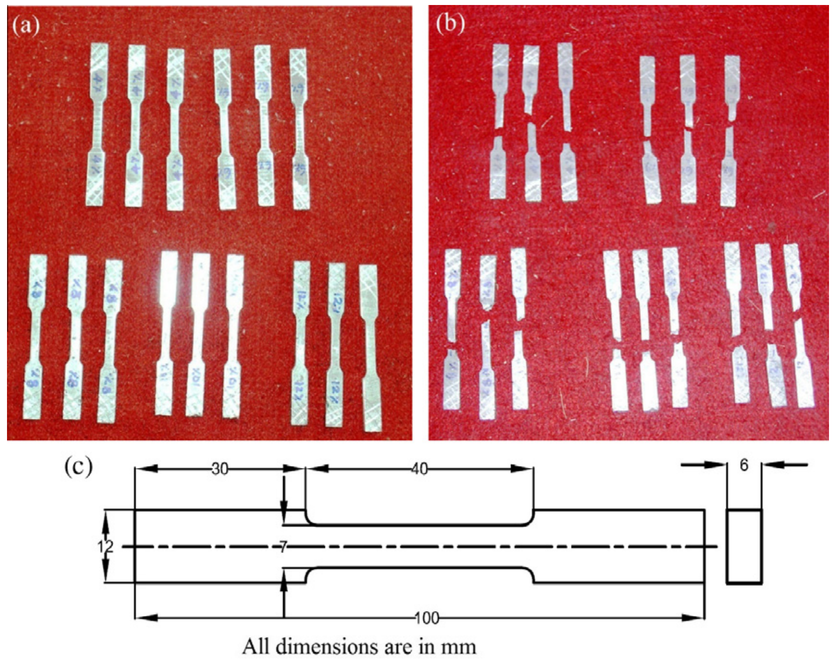

Fig. 3. Tensile specimens of AA6061–B_4C composites: (a) before test, (b) after test, and (c) the dimensions of tensile specimen.

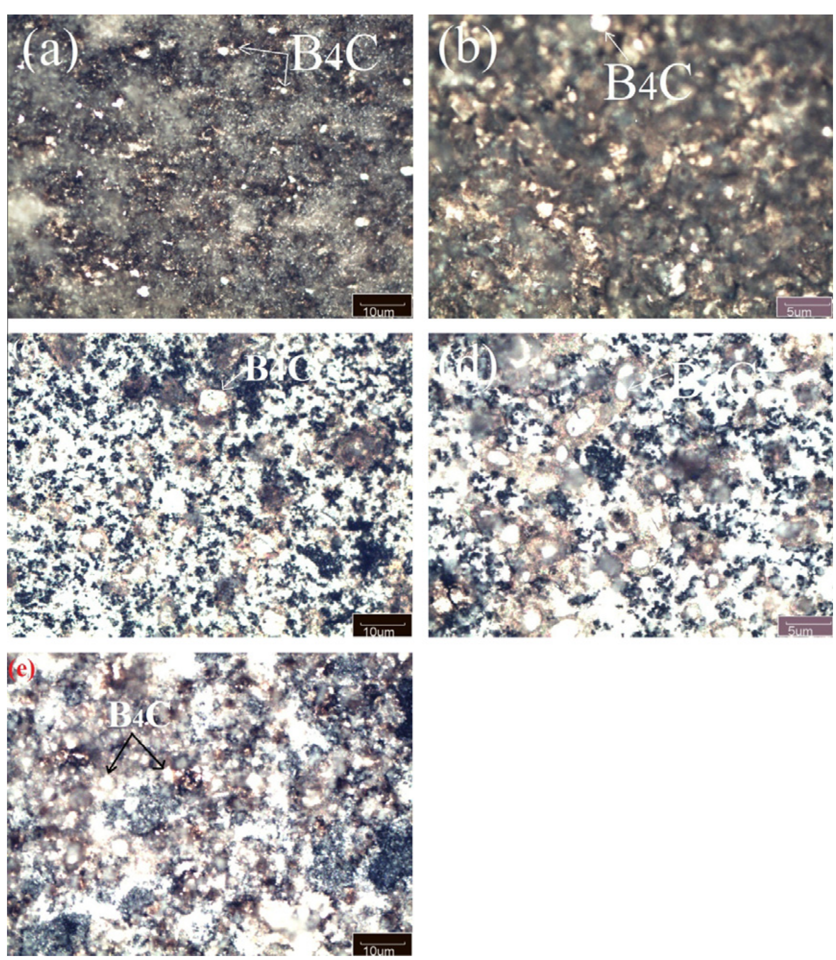

Fig. 4. Photomicrographs of the cast AA6061–B_4C AMCs: (a) 4% B_4C, (b) 6% B_4C, (c) 8% B_4C, (d) 10% B_4C, and (e) 12% B_4C.

the microstructure in this study was 2–3 g sodium molybdate, 5 ml HCl (35%) and 1–2 g ammonium bifluoride in 100 ml distilled water. The specimens were immersed at room temperature until the surface was colored [17]. X-ray diffraction patterns were obtained using Panalytical X-ray diffractometer.

The hardness was measured at different locations. The microhardness of polished samples was measured using Vicker hardness Tester (Mitutoyo MVK-H1) at a load of 300 g for 10 s. The macrohardness was measured using Brinell Hardness Tester (model 7KB3000) at a load of 500 kg for a period of 15 s.

The tensile specimens were prepared as per ASTM E08 standard [18]. The dimensions of the specimen are shown in Fig. 3. The ultimate tensile strength (UTS) was estimated using a computerized Universal Testing Machine (TUE-C-1000).

3. Results and discussion

3.1. Evaluation of microstructure

Aluminum reinforced with B_4C particulate composites are successfully fabricated by modified stir casting process. The application of stir casting method to fabricate aluminum reinforced with variety of ceramic particles is limited owing to poor wettability. The K_2TiF_6 flux has improved the wettability of B_4C particle with molten aluminum. The incorporation of B_4C particle in the Al matrix is facilitated by the flux. The flux reacts on the melted surface of B_4C particle and produces Ti compounds around the surface of B_4C particles. This reaction is exothermic in nature and heat is evolved in the vicinity of B_4C particle–melt interface. This local increase in temperature enhances the incorporation of particles into the melt and bonding with the matrix.

The optical photomicrographs of the fabricated AMCs are shown in Fig. 4a–e. It is observed from the figure that B_4C particles are dispersed uniformly in the aluminum matrix at all weight percentage which may be due to the equal value of density of matrix and reinforcement material causing the particle neither float nor decent in the mixture. The size of the B_4C particles appears to be uniform throughout the aluminum matrix. This can be attributed to the effective stirring action and the use of appropriate process parameters. Homogeneous distribution of particles is a prerequisite to enhance the mechanical properties of the matrix alloy.

Fig. 5a–e shows scanning electron micrograph of fabricated AMCs. The SEM images reveal that the homogeneous dispersion of B_4C particles in the matrix. However, in some region in Fig. 5d, the weak Ti compound layer is observed. The presence of week Ti compound is also evident from EDAX analysis and is depicted in Fig. 5d and f respectively. During the solidification of composites the Aluminum dendrites solidify first and the particles are rejected by the solid–liquid interface. Hence, the particles are segregated at the inter dendrite region [10]. Ti compound reaction layer was formed when adding K_2TiF_6 flux into the melt where K and F contributed for removing the oxide film from the Al surface [14]. The weak reaction layer in the region was not so clear in the SEM image due to the removal of interfacial reaction layer during polishing.

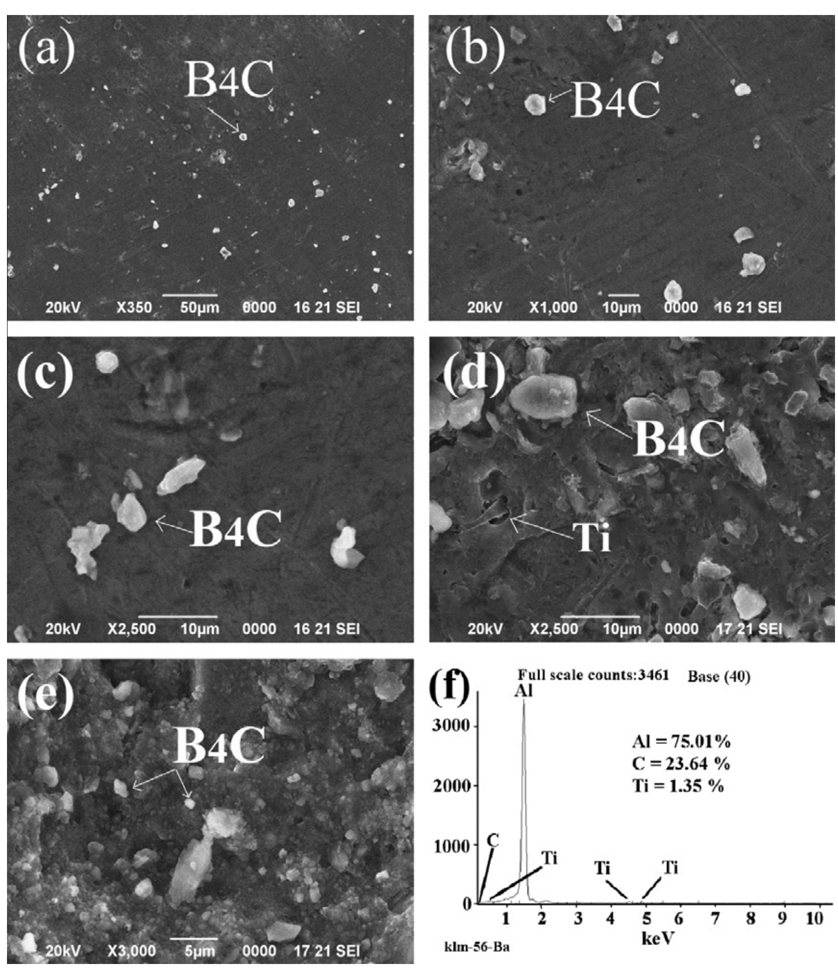

Fig. 5. SEM photomicrographs of castAA6061–B_4C composites: (a) 4% B_4C, (b) 6% B_4C, (c) 8% B_4C, (d) 10% B_4C, (e) 12% B_4C, and (f) EDAX analysis of 10% B_4C.

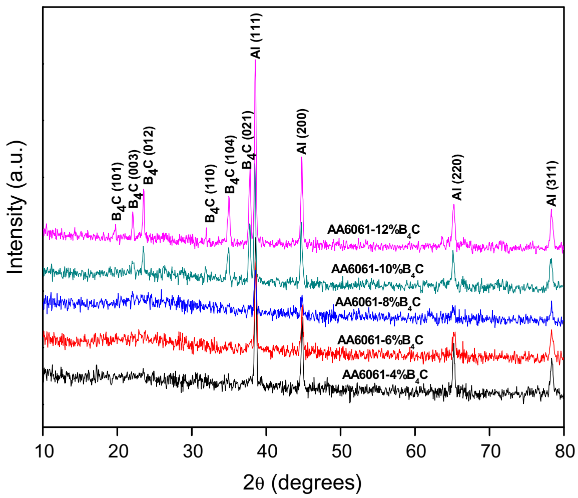

Fig. 6. XRD patterns of AA6061–B_4C composites.

3.2. XRD analysis of the AMCs

XRD analysis presented in Fig. 6 confirms the presence of B_4C reinforcement within the matrix. The peak of B_4C is increasing with increased B_4C content while the peak of Al is decreasing. It is also interesting to note that the peak of Al in the composite is slightly shifted to lower 2θ when compare to that of Al. It is also evident from the XRD pattern that the B_4C particles did not react with Al matrix and produced any other compounds. The B_4C particles are thermodynamically stable at the synthesizing temperature used in this work. This may be due to the formation of Ti compound layer around B_4C particles which tend to act as a reaction barrier and prevents the interfacial reactions between the B_4C and aluminum matrix.

3.3. Evaluation of mechanical properties

The mechanical properties of matrix alloy AA6061 is improved upon B_4C incorporation. Fig. 7 shows relation between weight percentage of B_4C reinforcement particulates and hardness of fabricated AMCs. It is observed that the micro and macrohardness of AMCs are linearly increasing when the reinforcement particulates increases. Addition of reinforcement particles in the matrix increases the surface area of the reinforcement and the matrix grain sizes are reduced. The presence of such hard surface area of particles offers more resistance to plastic deformation which leads to increase in the hardness of composites. It is reported [3] that the presence of hard ceramic phase in the soft ductile matrix reduces the ductility of composites due to reduction of ductile metal content which significantly increases the hardness value.

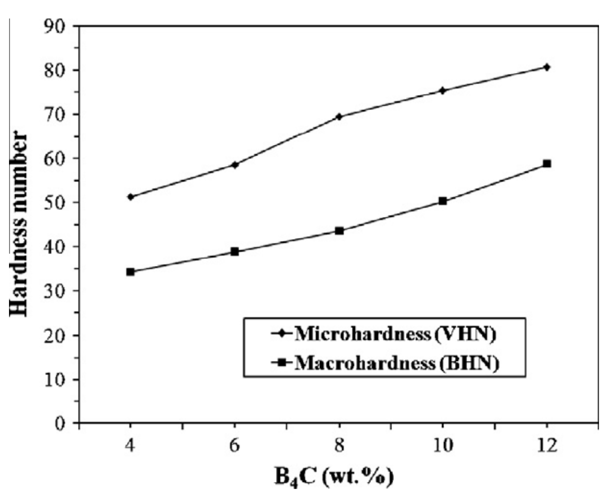

Fig. 7. The effect of amount of B_4C particulates on the hardness of stir casted AMCs.

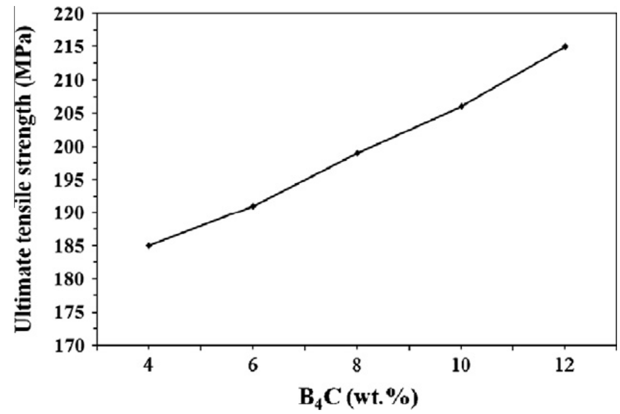

Fig. 8. The effect of the amount of B_4C particulates on the tensile strength of stir casted AMCs.

Fig. 8 shows the relation between tensile strength of the fabricated composites and the weight percentage of B_4C particulates. It can be inferred that B_4C particles are very effective in improving the tensile strength of composites from 185 MPa to 215 MPa. It may be due to the strengthening mechanism by load transfer of the reinforcement [19]. The addition of B_4C particles in the matrix induces much strength to matrix alloy by offering more resistance to tensile stresses. It is well known that the thermal expansion coefficient of B_4C particle is 5×10^{-6}/°C and for aluminum alloy is 23×10^{-6}/°C. The thermal mismatch between matrix and the reinforcement causes higher dislocation density in the matrix and load bearing capacity of the hard particles which subsequently increases the composites strength [14].

4. Conclusions

The Al–B_4C composites were produced by modified stir cast route with different weight percentage (viz 4, 6, 8, 10 and12) of reinforcement and the microstructure, mechanical properties were evaluated. From this study, the following conclusions are derived.

a. Production of Al–B_4C composites was completed successfully.
b. The Optical, SEM metallographic study and XRD analysis revealed the presence of B_4C particles in the composite with homogeneous dispersion.
c. The micro and macrohardness of the composites were increased from 51.3 HV to 80.8 HV and 34.4 BHN to 58.6 BHN with respect to addition of weight percentage of B_4C particles.
d. The reinforcement of particle has enhanced the tensile strength of aluminum matrix and composites from 185 MPa to 215 MPa.

Acknowledgements

The authors would like to thank the Management and Welding Research Cell, Department of Mechanical Engineering, Coimbatore Institute of Technology, Coimbatore, INDIA for providing the facilities to fabricate AMCs. The authors are grateful to Karunya University for providing SEM, UTM testing facilities and to Mr. S. Gopalakrishnan, Mr. S.J. Vijay and Mr. I. Dinaharan for their technical support offered to execute the research work.

References

[1] Hemanth Joel. Quartz (SiO_2P) reinforced chilled metal matrix composite (CMMC) for automobile applications. Mater Des 2009;30:323–9.

[2] Feng YC, Geng L, Zheng PQ, Zheng ZZ, Wang GS. Fabrication and characteristic of Al-based hybrid composite reinforced with tungsten oxide particle and aluminum borate whisker by squeeze casting. Mater Des 2008;29:2023–6.

[3] Ramesh CS, Keshavamurthy R, Channabasappa BH, Abrar Ahmed. Microstructure and mechanical properties of Ni–P coated Si_3N_4 reinforced Al6061 composites. Mater sci Eng A 2009;502:99–106.

[4] Lashgari HR, Sufizadeh AR, Emamy M. The effect of strontium on the microstructure and wear properties of A356–10%B_4C cast composites. Mater Des 2010;31:2187–95.

[5] Altinkok N, Koker R. Modelling of the tensile and density properties in particle reinforced metal matrix composites by using neural networks. Mater Des 2006;27:625–31.

[6] Kaczmar JW, Pietrzak K, Wlosinski W. The production and application of metal matrix composite materials. J Mater Process Technol 2000;106:58–67.

[7] Ravi KR, Sreekumar VM, Pillai RM, Chandan Mahato, Amaranathan KR, Arul kumar R, et al. Optimization of mixing parameters through a water model for metal matrix composites synthesis. Mater Des 2007;28:871–81.

[8] Shorowordi KM, Laoui T, Haseeb ASMA, Celis JP, Froyen L. Microstructure and interface characteristics of B_4C, SiC, and Al_2O_3 reinforced Al matrix composites: a comparative study. J Mater Process Technol 2003;142:738–43.

[9] Kerti I, Toptan F. Microstructural variations in cast B_4C-reinforced aluminium matrix composites (AMCs). Mater Lett 2008;62:1215–8.

[10] Kok M. Production and mechanical properties of Al_2O_3 particle-reinforced 2024 aluminium alloy composites. J Mater Process Technol 2005;161:381–7.

[11] Hashim J. The production of cast metal matrix composite by a modified stir casting method. J Teknol 2001;35(A):9–20.

[12] Gopalakrishnan S, Murugan N. Prediction of tensile strength of friction stir welded aluminium matrix TiC_p particulate reinforced composite. Mater Des 2011;32:462–7.

[13] Abenojar J, Velasco F, Martinez MA. Optimization of processing parameters for the Al + 10%B_4C system obtained by mechanical alloying. J Mater Process Technol 2007;184:441–6.

[14] Toptan F, Kilicarslan A, Cigdem M, Kerti I. Processing and microstructural characterization of AA1070 and AA 6063 matrix B_4C_P reinforced composites. Mater Des 2010;31:S87–91.

[15] Hashim J, Looney L, Hashmi MSJ. Metal matrix composites: production by the stir casting method. J Mater Process Technol 1999;92–93:1–7.

[16] Sevik H, Can kurnaz S. Properties of alumina particulate reinforced aluminium alloy produced by pressure die casting. Mater Des 2006;27:676–83.

[17] Vijay SJ, Murugan N. Effect of tool pin profile on the metallurgical and tensile properties of friction stir welded Al–TiB_2metal matrix composite. Mater Des 2010;31:3585–9.

[18] ASTM Standard E8. Standard test method for tension testing of metallic materials. West Conshohocken (USA): ASTM International; 2004.

[19] Feng YC, Geng L, Fan GH, Li AB, Zheng ZZ. The properties and microstructure of hybrid composites reinforced with WO_3 particles and $Al_{18}B_4O_{33}$ whiskers by squeeze casting. Mater Des 2009;30:3632–5.